A bottom-driven mechanism for distributed faulting in the Gulf of California Rift

Geo PRISMS — Geodynamic Processes at Rifting and Subducting Margins

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Introduction

Observations in the continent-ocean transition of the Gulf of California (GOC) show multiple oblique-slip faults distributed in a 200x70 km^2 area (Fig. 4). In contrast, north and south of this broad pull-apart structure, major transform faults accommodate plate motion. We propose that the mechanism for distributed faulting results from the boundary conditions present in the GOC, where basal shear is distributed between the southernmost fault of the San Andreas system and the Ballenas Transform fault.

We hypothesize that in oblique-extensional settings whether deformation is partitioned in a few dip-slip and strike-slip faults, or in numerous oblique-slip faults may depend on **(1)** bottom-driven, distributed extension and shear deformation of the lower crust/upper mantle, and **(2)** the rift obliquity. We explore the effects of bottom-driven shear on the deformation of an elastic-plastic layer with the help of pseudo-three dimensional numerical models that include side forces.

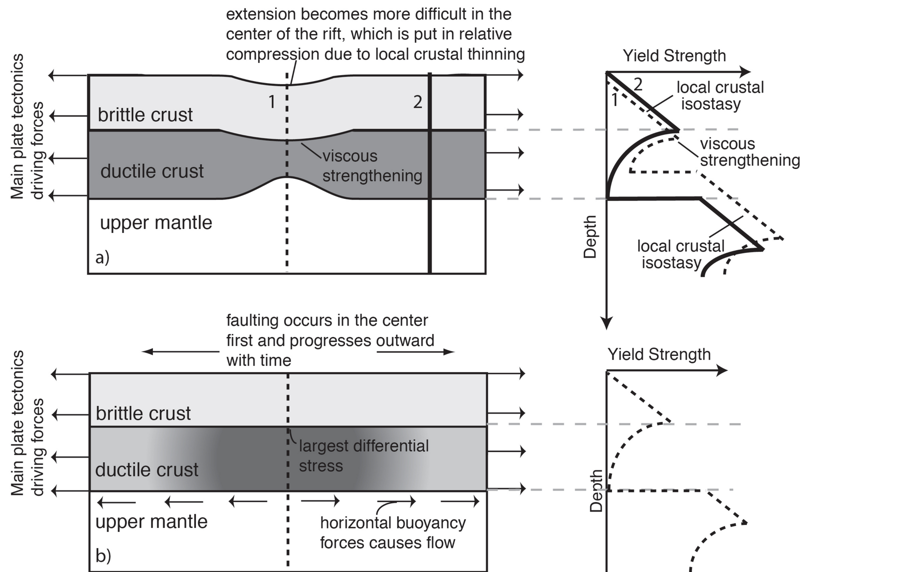


FIG. 1. a) Edge-driven models of deformation assume that mainly normal stresses at the edge of plates are important for driving deformation. **b)** Bottom-driven models of deformation assume that in addition to the edge forces, flow in the lower crust and mantle is significant for determining the style of deformation.

Analytical Model of Channel Drag

FIG. 2

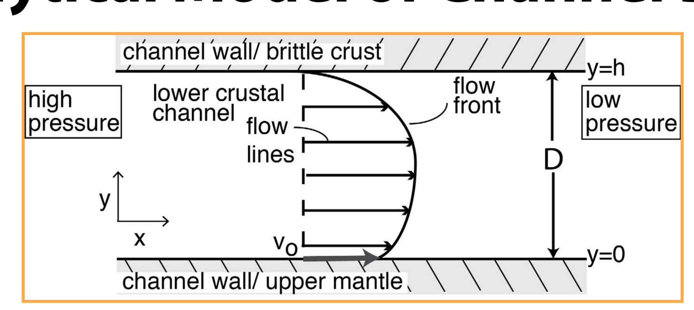
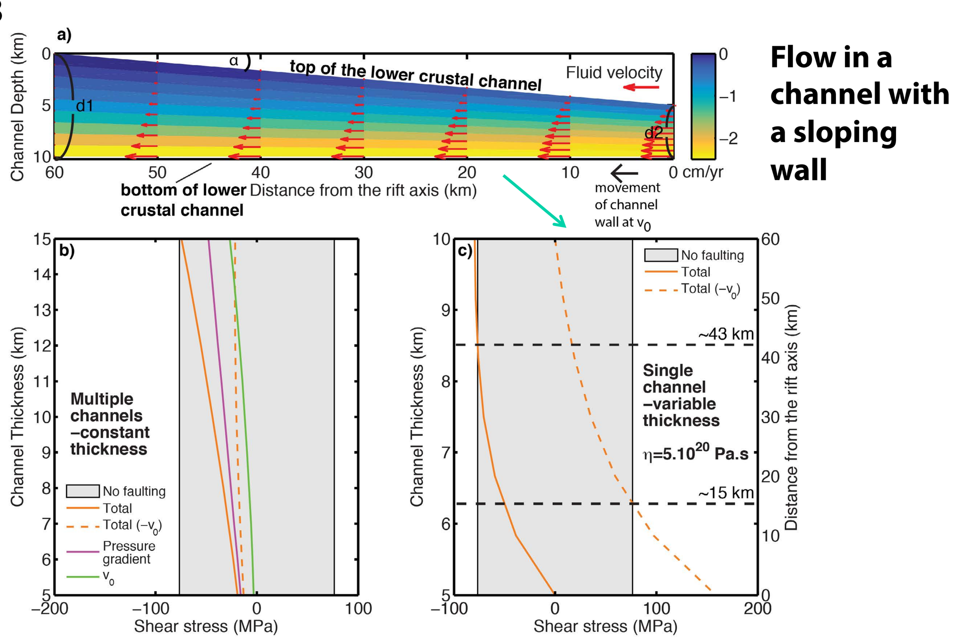


FIG. 3



Flow in a channel with a sloping wall

Shear stress at the base of the brittle crust for 1D Couette-Poiseuille channel flow with a constant channel thickness.

Shear stress at the base of the brittle crust for flow in a channel with a sloping wall shown in **(a)**.

Modeling strain partitioning and distribution of deformation in oblique rifts

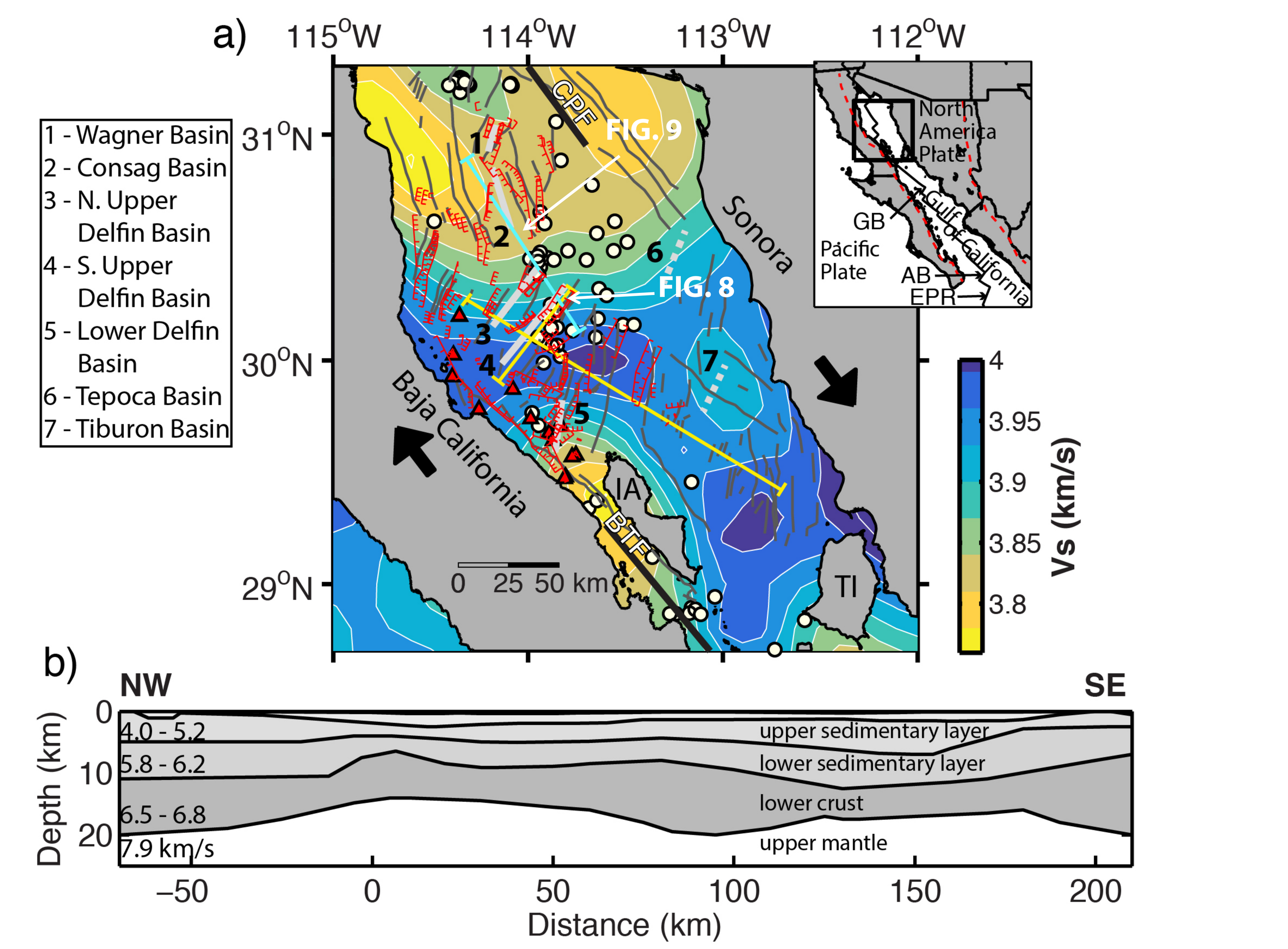


FIG 4. a) Grid of the average S-wave velocities at 20-30 km depth (contour interval=0.03 km/s) beneath the N. Gulf of California from Persaud et al. (2015). Faults (gray) interpreted in deep seismic reflection data after Martín-Barajas et al. (2013). White circles are relocated earthquakes from Sumy et al. (2013). Thick black arrows indicate Pacific-North America relative plate motion. Red dashed lines in the inset map show the extent of the Gulf Extensional Province. **b)** 2D V_P model from Gonzalez-Fernandez et al. (2005); ~0–180 km extends along the profile marked with the longer yellow line in a).

OBSERVATIONS:

- Active faulting is distributed across multiple faults in a broad plate boundary zone.
- No transform fault.
- Evidence for lower crustal flow.

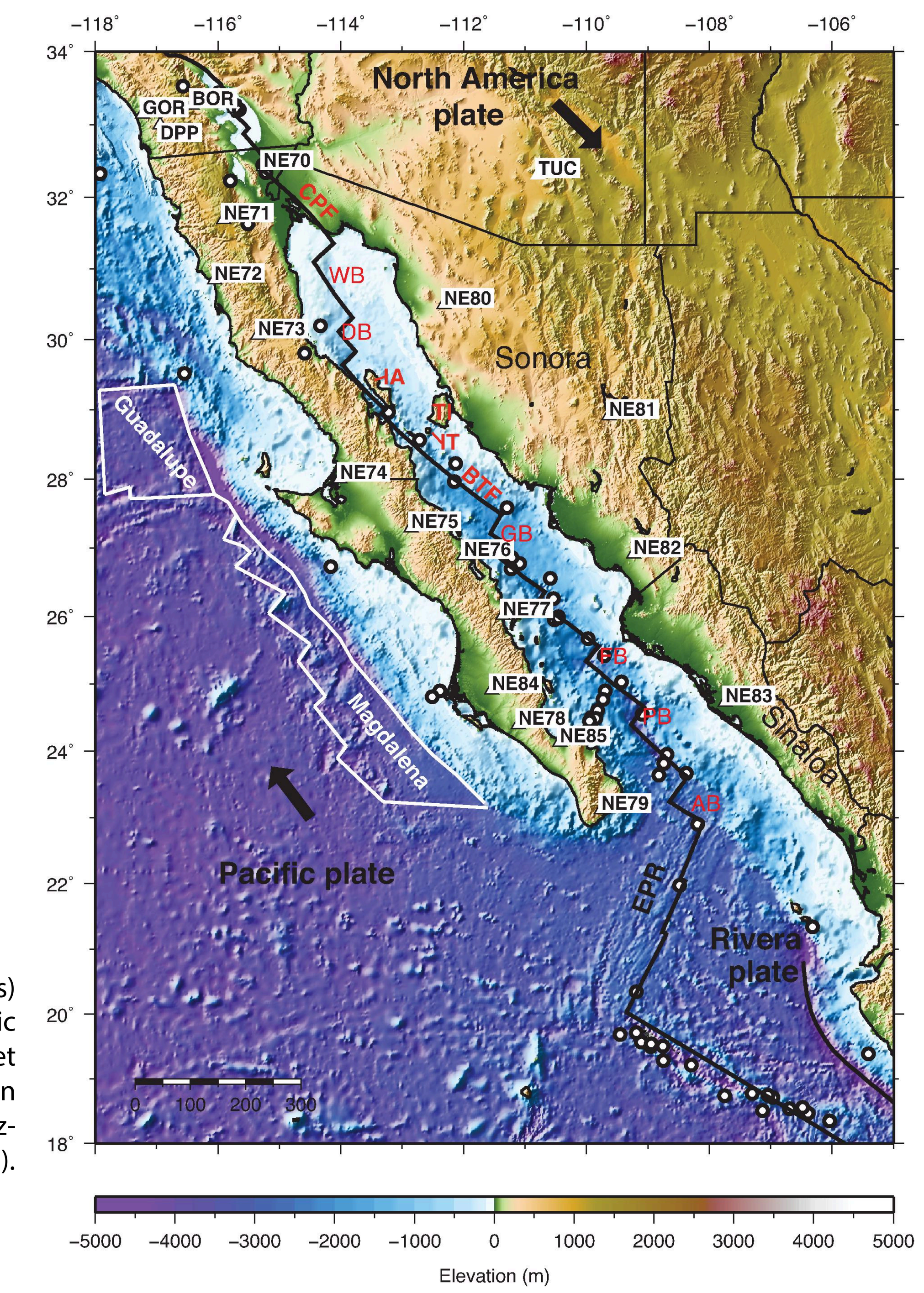


FIG 5. Map of the Gulf of California from Di Luccio et al. (2013). Black arrows indicate the relative Pacific-North America plate motion. Thick white lines show the Magdalena and the Guadalupe plates. Labeled seismic stations and some of the regional earthquakes (white) used in in the surface wave study of Di Luccio et al (2013) are shown. Features in the Gulf are labeled in red; CPF: Cerro Prieto fault; WB: Wagner basin; DB: Delfin basin; BTF: Ballenas Transform fault; IA: Isla Angel de la Guarda; TI: Tiburon Island; GB: Guaymas basin; IT: Isla Tortuga; FB: Farallon basin; PB: Pescadero basin; AB: Alarcón basin; EPR: East Pacific Rise.

2+½D Numerical Models

DISTRIBUTED FAUTING IN A BRITTLE 5-KM THICK UPPER CRUSTAL LAYER OVERLYING A 15-KM THICK LOWER CRUSTAL CHANNEL

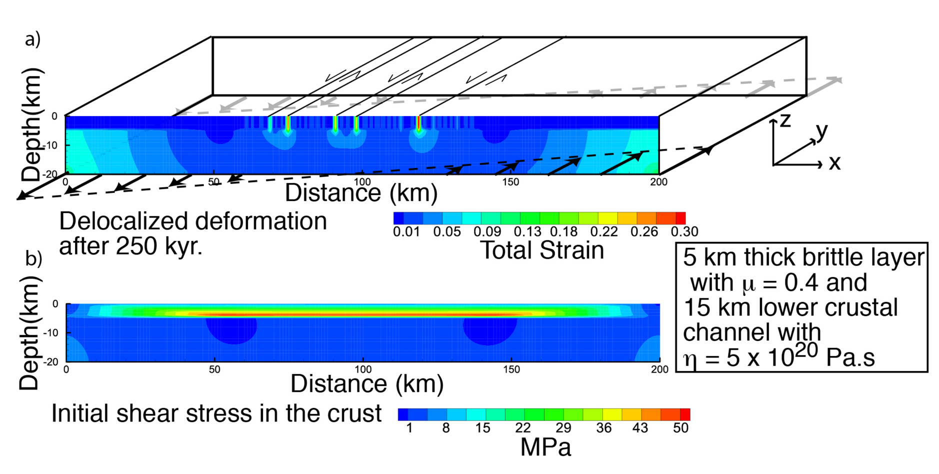
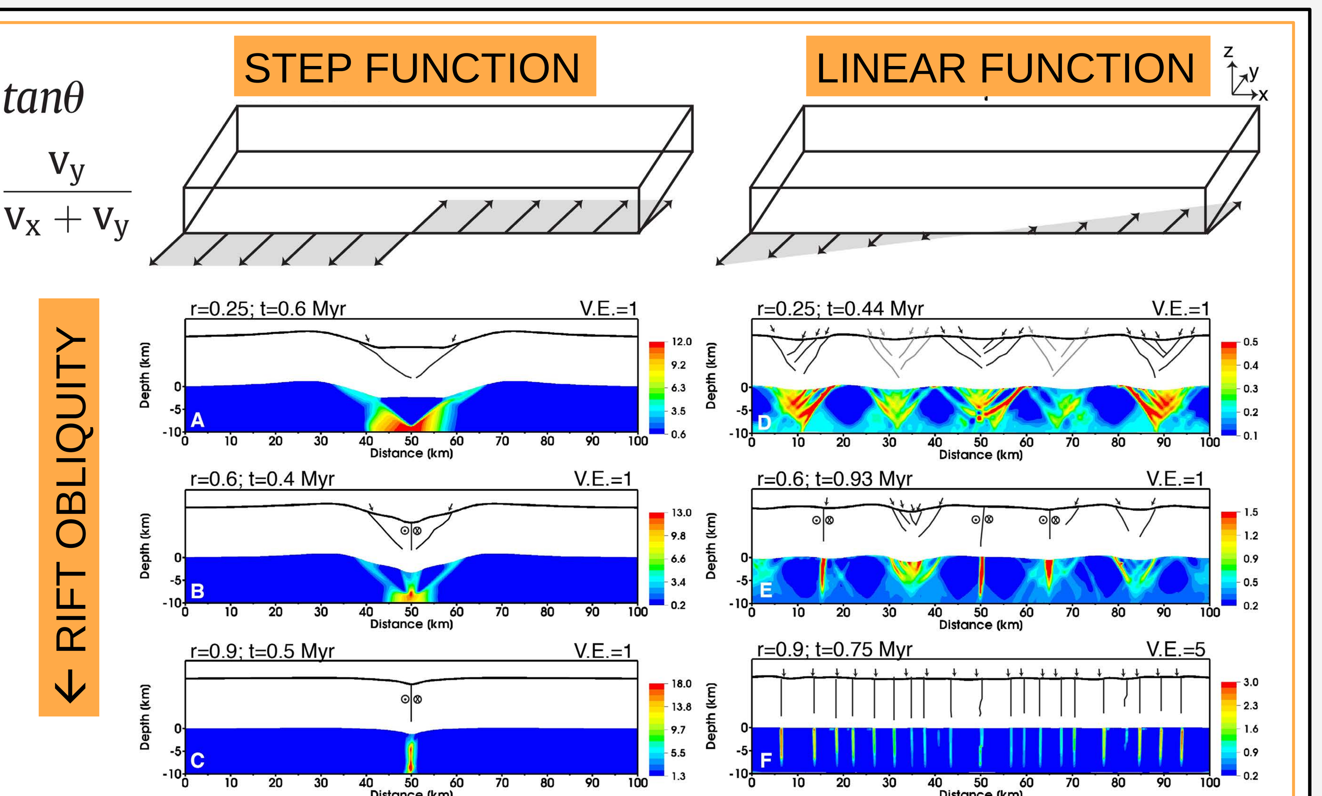


FIG 6. a) Accumulated plastic strain after 250 Kyr and **b)** initial shear stress for a numerical model with a 5-km thick brittle layer. The viscosity of the lower crustal channel is 5x10^{20} Pa.s, and linear velocity boundary conditions are applied at the base of the lower crust.

$$\frac{1-r}{r} = \tan\theta$$

$$r = \frac{v_y}{v_x + v_y}$$



r	v_x(cm yr^{-1})	v_y (cm yr^{-1})	θ(°)	α(°)
0.25	2.47	0.82	72	9
0.6	1.44	2.16	34	28
0.7	1.02	2.39	23	33
0.9	0.29	2.58	6	42

FIG 7. Models with varying obliquity labeled in the top left of each model. The time for each model run, t, is indicated next to the obliquity. The vertical exaggeration of the topography is noted at the top right of each panel. The total plastic strain (x 100%) is shown in all cases with hot colors representing zones of high strain.

Application to the Northern Gulf

- Our model with an obliquity of 0.7, and linear basal velocity boundary conditions reveals a delocalized fault pattern of contemporaneously active faults, multiple rift basins and variable fault dips representative of faulting in the N. Gulf.
- The r=0.7 model is able to broad geometrical arrangement of the two Upper Delfin, Lower Delfin and Wagner basins as segmented basins with tilted fault blocks, and multiple oblique-slip bounding faults characteristic of incomplete strain-partitioning. We also confirm with our numerical results that numerous oblique-slip faults accommodate slip in the study area instead of throughgoing large-offset transform faults.

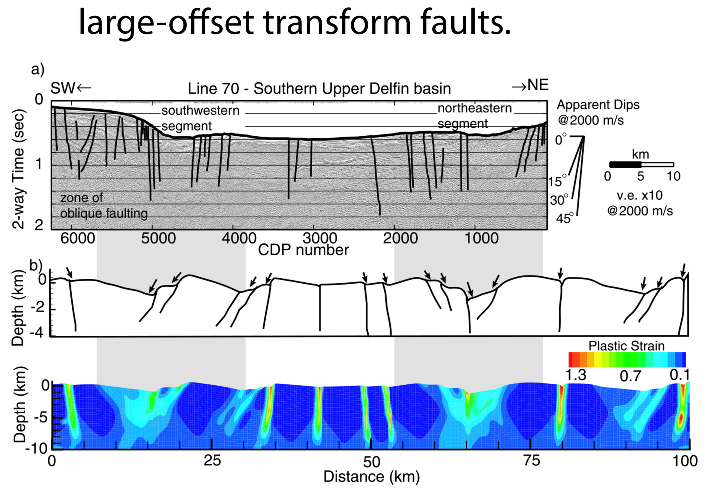
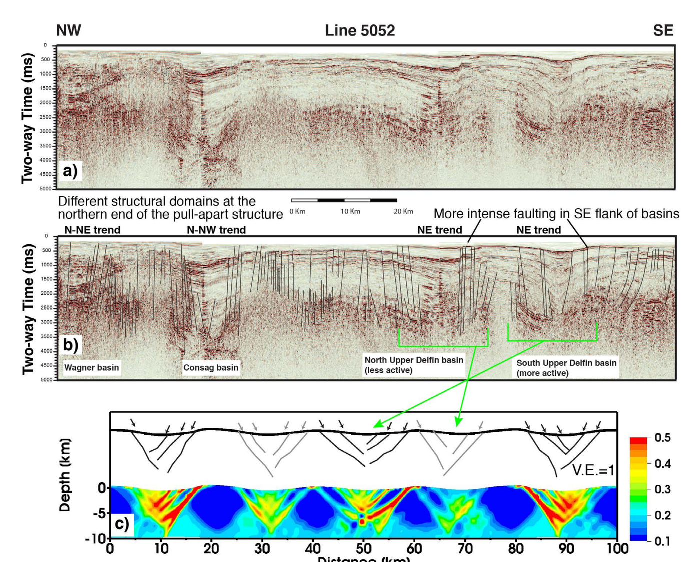


FIG 8. Comparison between **a)** a representative seismic profile across the northern Gulf from Persaud et al. (2003), and **b)** a 800,000-yr model run with linear basal-boundary conditions, and r=0.7 (θ = 23°). The shorter yellow line in **Fig. 4a** marks the location of the seismic profile.

FIG 9. a-b) Comparison between a deep seismic profile across the N. Gulf from Sojo-Amezquita (2012), and **c)** a 440,000-yr model run with linear basal-boundary conditions, and r=0.25 (θ = 72°) (**Fig. 7d**). The seismic profile location is marked with a cyan line in **Fig. 4a**, and is obliquely oriented with respect to the basin axes. The horizontal scales in a), b) and c) are approximately the same. The vertical exaggeration in a) and b) is roughly 3 in the sedimentary layers and 4 in the basement.



Conclusions

1. Strain localization results in our models when the basal shear abruptly increases in a step-function manner while oblique-slip on numerous faults dominates for distributed basal shear **(Fig. 7)**.
2. We show in a 2-layer numerical model that lower crustal flow can produce multiple faults in the overlying brittle crust in the case of distributed basal shear **(Fig. 6)**. In this instance, the flow essentially drives the deformation.
3. We further explore how the faulting style varies with obliquity and demonstrate that the delocalized faulting is reproduced in models with an obliquity of 0.7 and distributed basal shear boundary conditions **(Fig. 8 and 9)**, consistent with GOC observations.

References

Persaud P., E. Tan, J. Contreras and L. Lavier, (2016) A bottom-driven mechanism for distributed faulting in the Gulf of California Rift, Tectonophysics, http://dx.doi.org/10.1016/j.tecto.2016.11.024 (in press - Special Tectonophysics issue on the Gulf of California).

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